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AUTHOR(S): R.J. Commisso, W.T. Armstrong, J.C. Caldwell, C.A. Ekdahl
J. Lipson, R.K. Linford, E.G. Sherwood, R.E. Siemon, and
M. Tuszewski

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LOS ALAMOS SCIENTIFIC LABORATORY
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The Initial Ionization Stage of FRC Formation

R. J. Commisso, W. T. Armstrong, J. C. Cochrane, C. A. Ekdahl,* J. Lipson, R. K. Linford, E. G. Sherwood, R. E. Siemon, and M. Tuszewski

Introduction

A Field-Reversed Configuration (FRC) is a prolate compact torus that is confined by poloidal fields only. Theta-pinch formation of an FRC employs an initial bias field, B_1, whose direction is opposite to that of the main theta-pinch field.[1] Some fraction of the flux associated with this bias field eventually constitutes the closed-field-line flux of the FRC. Experimental and theoretical evidence suggest that the longest-lived FRC's are obtained when the closed flux is maximized. Because the initial ionization is done in the presence of the bias field, the actual bias flux available at the time of application of the main theta-pinch field depends strongly on the initial ionization, or "preionization," technique used.[2] In this paper we report on experiments characterizing the previously used theta-pinch preionization technique that employed a net field (bias plus preionization) null, or "zero-crossing," of the axial component of the magnetic field to break down the gas. We also discuss results of experiments designed to develop preionization techniques in which the gas breakdown is not accomplished by a zero-crossing.

Characterization of Zero-Crossing Preionization

A study of the effect of the zero-crossing preionization scheme on the initial bias flux was carried out on FRX-B. The FRX-B device is a 100-cm long theta pinch of 22-cm i.d. Internal magnetic field probes sensitive to the axial component of the magnetic field and compensated diamagnetic loops for measuring the plasma diamagnetism were the principal diagnostics used. The 400-kHz theta-pinch preionization was done with the zero-crossing mode (see Ref. 2 for details).

The probe data indicate that at the field zero-crossing a gas breakdown occurs and a plasma ring or annulus forms at the wall and subsequently implodes. The annulus then undergoes an oscillation around an equilibrium radius determined by the amount of trapped flux within the annulus. A numerical code which includes damping by ion-neutral collisions and finite (classical) resistivity was also developed to model the observed properties of the plasma during preionization.[2] Figure 1 is a comparison of the code prediction and experimental data for the ratio of flux inside the plasma annulus, ϕ_1, to the vacuum flux associated with the bias field, ϕ_0, as a function of time. As time proceeds, the ratio approaches 0.5. Thus, only half

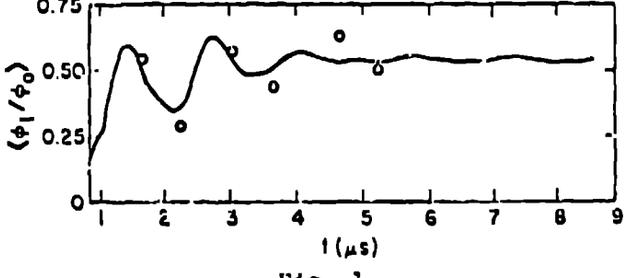

Fig. 1.
Comparison of measured normalized trapped bias flux with code predictions. Circles are measured values and solid line is code prediction.

*Permanent Address: Mission Research Corporation, 1400 San Mateo SE, Albuquerque, NM 87108

of the total possible bias flux is available at the time of the main discharge. We have assumed that the flux outside the annulus is lost during the main discharge. This assumption has been substantiated by further probe measurements.[2,3] Evidently, the conductivity of the plasma annulus inhibits the bias field from diffusing through it.

Alternative Ionization Schemes

The results outlined in the previous section suggest that a preionization scheme which does not use a net field null to break down the gas could be beneficial in optimizing the trapped bias flux. The possibility of photoionization has been evaluated[4] with the result that very large energy-storage capabilties are required in order to provide a sufficient percentage of ionization. Because eventual translation and trapping of the FRC necessitates a puff-fill from one end, possibilities for electrode (z-pinch) type ionization are limited. Among various electrodeless discharges, we have chosen to study experimentally a quadrupole system. The induced ionizing current in this system is parallel to the bias field eliminating the need for a zero-crossing. A low amplitude (compared to the bias) theta-pinch was also studied as a part of a multistage scheme. These studies were carried out on the FRX-A device which has the same physical dimensions as FRX-B.

a. Unassisted quadrupole

The quadrupole experiments[5-7] show a high degree of ionization (60-80%) for values of the quadrupole magnetic field (B_{4p}) comparable to the bias magnetic field, B_1; however, density build-up is inhibited for $B_{4p} < B_0$. The density build-up is correlated with gross compressional effects. Moreover, the plasma maintains the quadrupole symmetry. These results suggest that by increasing B_{4p}, ionization could be achieved at higher values of B_1. However, the ionization would probably be accompanied by excessive heating and an unwanted quadrupole structure embedded in the plasma. We therefore began experiments with a multistage system.

b. Multistage system

The multistage system employs a sequence of discharges to provide adequate seed ionization for the low amplitude theta pinch to couple to the gas without the undesirable zero crossing.[7] The discharges consist of a 36-MHz, ~10-kW RF generator; a 1-kG, 160-kHz quadrupole; and a ~2-kG, 520-kHz theta pinch. The sequencing begins with RF break down of the gas so that visible light is detected. After ~10 μs of light emission the quadrupole is fired and clamped after one half cycle. The theta pinch is fired at the quadrupole current peak. This sequence was found to result in the most reproducible discharges and the highest level of ionization. In Fig. 2 the unassisted quadrupole

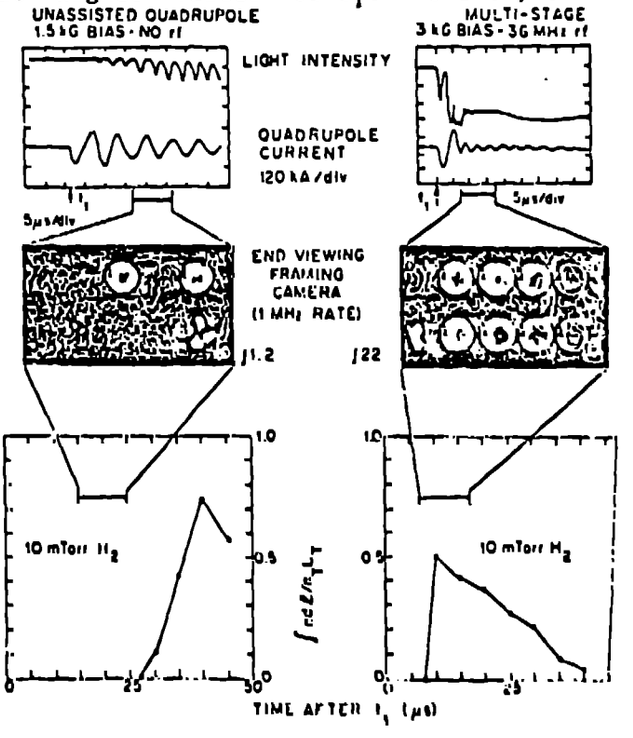

Fig. 2.
Comparison of unassisted quadrupole and multistage systems.

and multistage system are compared. As can be seen from the end-view framing camera photographs in the figure, the quadrupole structure in the plasma becomes circumfused when the theta pinch is added. Emission from the CIII 2296Å line indicates an electron temperature $\lesssim$ 10 eV.

We found it possible to achieve sufficient preionization without the quadrupole phase of the multistage system. This result is illustrated in Fig. 3. The value of the bias field must be reduced some ~700-800 G to obtain the same ionization as is achieved when the quadrupole is included in the multistage scheme. Using this scheme without the quadrupole, ionization has been obtained for $B_1 \lesssim 3$ kG at a fill pressure of 10 mT and for $B_1 \lesssim 3.5$ kG at a 20 mT fill. The CIII emission is associated with the density buildup and again indicates an electron temperature of $\lesssim$ 10 eV.

The RF phase of this scheme is critical in obtaining ionization. This behavior is observed whether or not the quadrupole is used and is illustrated in Fig. 4. When the RF does not couple to the neutral gas, as determined by visible light emission, no density build-up is observed. The optimum RF antenna configuration consisted of ~3 turns of 1/4"-o.d. insulated wire positioned ~6 cm from each end of the main theta-pinch coil. In order to achieve reproducible RF coupling, an additional burst of ~70 MHz RF is sequenced to fire ~5 μs before the 36 MHz unit. The 70 MHz RF is generated by a ferrite core driven to saturation by a capacitor discharge (0.25μf at 25kV) and is coupled to the gas by a separate antenna consisting of a single turn of 1/4"-o.d. insulated wire placed just inside the 36 MHz antennas.

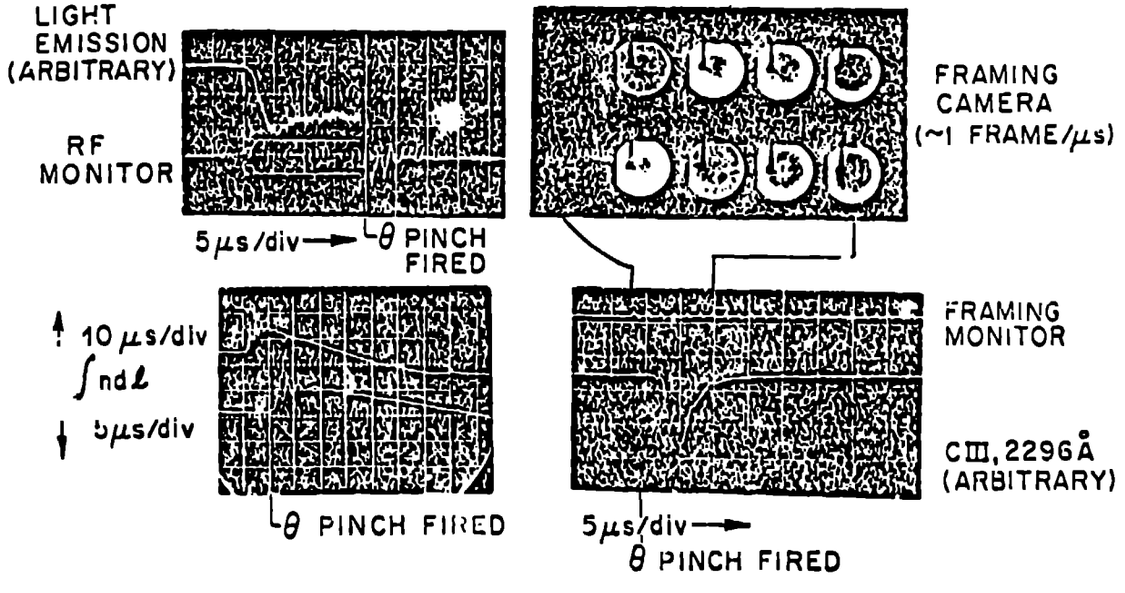

Fig. 3.
Multistage operation without quadrupole.

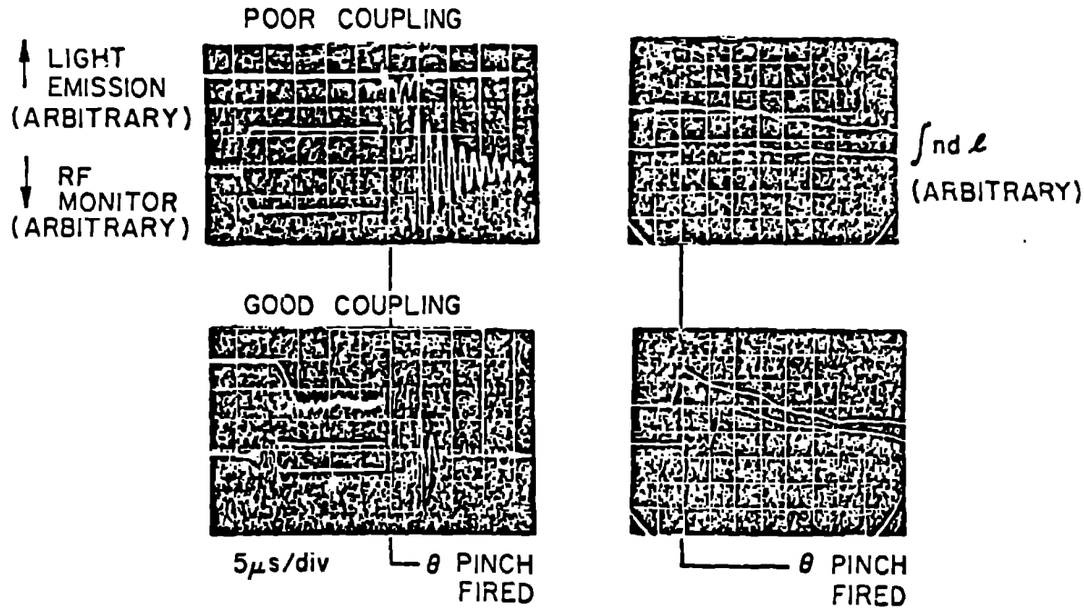

Fig. 4.
Effect of RF coupling on density build-up.

Summary

Only half of the total initial bias flux is available at the time of the main discharge when the zero-crossing theta-pinch preionization scheme is used. Preionization schemes which avoid a zero-crossing to ionize the gas have been successful in producing an initial plasma in the presence of the bias field. Measurements to determine the amount of bias flux trapped in plasmas so produced are in progress.

References

1. W. T. Armstrong, R. K. Linford, J. Lipson, and E. G. Sherwood, accepted by Phys. Fluids, 1980.
2. W. T. Armstrong, J. C. Cochrane, R. J. Commisso, J. Lipson, and M. Tuszewski, submitted to App. Phys. Lett., 1980.
3. W. T. Armstrong, J. C. Cochrane, J. Lipson, R. K. Linford, A. G. Sgro, E. G. Sherwood, R. E. Siemon, and M. Tuszewski, "FRC Studies on FRX-B," Proceedings of this conference.
4. C. A. Ekdahl and R. J. Commisso, Los Alamos Scientific Laboratory report LA-UR-80-2233.
5. C. A. Ekdahl, R. J. Commisso, R. K. Linford, and E. G. Sherwood, Los Alamos Scientific Laboratory report LA-UR-80-134.
6. R. J. Commisso, C. A. Ekdahl, R. K. Linford, and E. G. Sherwood, Proceedings of 1980 IEEE Conference on Plasma Science, Madison, WI, Paper 5A10 (1980).
7. R. J. Commisso, C. A. Ekdahl, E. G. Sherwood, and R. E. Siemon, Bull. Am. Phys. Soc. 25, 1021 (1980).